

SUMMARY OF RESEARCH

for

CRYSTAL-FACE Polarization Lidar Research

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submitted by

Kenneth Sassen, PI

Geophysical Institute

University of Alaska Fairbanks

Fairbanks, Alaska 99775

ksassen@gi.alaska.edu

1. Introduction

The University of Alaska Fairbanks (UAF) Polarization Diversity Lidar (PDL, Sassen 1994) participated in the July 2002 CRYSTAL-FACE field campaign, shortly after the PI moved from the University of Utah to UAF. The truck-mounted PDL is an advanced dual wavelength (1.06 and 0.532 μm), high resolution (0.1-s by 1.5-m), scanning lidar system designed as a testbed for evaluating laser backscatter depolarization techniques for the study of clouds and aerosols in the atmosphere. The main goals identified in our proposal for the CRYSTAL-FACE experiment were, i) the characterization of Florida thunderstorm anvil macrophysical and microphysical properties from lidar backscattering and depolarization, ii) the study of thin to subvisual tropopause-topped subtropical cirrus, iii) the search for indirect cloud effects of trans-Atlantic advected Saharan dust storm aerosols on clouds, and iv) the investigation of melting layer effects on lidar and multi-wavelength Doppler radar measurements in precipitation.

Although we experienced adversity in the field during the campaign, sufficient data was collected to begin addressing these topics, and several conference presentations, three journal articles, and one book chapter have resulted from the data analysis effort supported by this grant. (PDL operations were delayed by FAA concerns over the initial sighting at the Kendall-Tamiami Airport, and a brief but major laser breakdown was experienced during the re-setup at the remote Ochopee Everglades site that also supported the N-POL radar.) All lidar data collected by the PDL system were processed and quality checked, and submitted to the CRYSTAL-FACE data archive in a timely manner.

2. Major Findings

We have worked actively with several CRYSTAL-FACE investigators on case study investigations. On request, time-height displays of laser backscattering and linear depolarization ratios were provided to several

investigators, including the 23-24 July 2002 anvil case study. Comparisons of lidar linear depolarization ratios (δ) between the PDL and the ER2 airborne Cloud Polarization Lidar (CPL) have been made (and are continuing) with NASA GSFC researchers, with the aim of determining if differences in δ , and hence in ice crystal shape, exist as a function of lateral distance from the generating thunderstorm cores. Because the δ values from both polarization lidar systems are low relative to several available midlatitude cirrus studies (see Sassen and Benson 2001), there are indications that these thunderstorm anvils contained unusual particle shapes, perhaps dominated by irregular nonspherical crystals (Campbell et al. 2005). We hope to soon submit an article to *Geophysical Research Letters* to finalize this study.

Probably the most interesting finding stemming from our lidar observations has been associated with an outbreak of Saharan Desert dust aerosol that was advected over southern Florida in the final days of the CRYSTAL-FACE campaign. The presence of the dust was indicated by an enhanced backscattering layer, which displayed δ values of 0.10 -0.15 indicative of large nonspherical particles, within the expected height range (~0 to 5.5 km MSL) for Saharan effects. The depolarization ratios were somewhat lower than those from Asian desert dusts transported to the Great Basin, but are consistent with micron-sized irregular particles (Sassen 2005). *In situ* ice nucleus measurements showed that the particles sampled by the lidar were highly effective ice nuclei (DeMott et al. 2003), again like their Asian counterparts. In one case, the PDL data indicated the brief glaciation of a mildly supercooled (~-5° to -9°C) altocumulus cloud layer that came into contact with the aerosol layer top, also suggesting the action of unusually active ice nuclei (Sassen et al. 2003; see Attachment 1).

This looked-for but fortuitous discovery has stimulated much modeling activity to determine the possible effects of these unusual aerosols on the dynamics, precipitation, and anvil contents of the CRYSTAL-FACE

thunderstorms during this brief period. Although diverse predictions have been made using various cloud models, it is logical to assume that those thunderstorms affected by the Saharan dust aerosol will display different distributions of supercooled cloud water and ice because the particles are such active ice nuclei, thereby potentially changing the storm dynamics and precipitation efficiency.

Finally, we completed an extensive investigation of another subject we had hoped to be able to study within the remote sensor-rich CRYSTAL-FACE experiment—namely, an improved characterization of the effects of melting hydrometeors on lidar and Doppler radar studies. The effects of the melting layer on radar, and later lidar, probing has been of interest for over fifty years, and is of even greater importance now that precipitation is being routinely studied from Earth orbit (i.e., TRMM and the upcoming CloudSat radar missions). Previous research has identified a prominent microwave radar bright band (enhanced backscattering) low in the melting layer, and even a millimeter-wave radar dark band (decreased backscattering) at the very top of the melting layer. Relatively recent lidar studies (Sassen and Chen 1995) found a persistent lidar dark band at about the same height as the microwave radar bright band. Many studies have attempted to explain these features using single or dual remote sensors at various wavelengths, but it is obvious that a complete explanation could only be found using a diverse group of state-of-the-art radar and lidar systems.

A unique opportunity to do this occurred during the early part of the CRYSTAL-FACE campaign, when conditions were right for more continuous rainfall that favored bright and dark band phenomena. The results are given in Sassen et al. (2005: see Attachment 2), which uses data from the S-band (10.6 cm), K-band (0.86 cm), and W-band (0.32 cm wavelength) Doppler radars, as well as the 0.523 μm Micropulse Lidar (MPL) stationed at the Kendall-Tamiami Airport. (Ironically, the more sophisticated PDL system was not allowed to operate

during this period, but the real-time displays of the versatile MPL gave clear indications that lidar melting layer phenomena were occurring.) Our findings essentially redefine many aspects of the previous theories developed to explain these remote sensing features of the melting layer.

It was demonstrated that in contrast to the ubiquitous S-band radar bright band, only intermittent evidence was found at K-band, and no clear examples of the radar bright band were seen at W-band frequencies because of the dominance of non-Rayleigh scattering effects. Analysis also revealed that the relatively inconspicuous W-band radar dark band results from non-Rayleigh effects in large water-coated snowflakes high in the melting layer. The lidar dark band exclusively involves mixed-phase particles and was centered where the shrinking snowflakes collapsed into raindrops, the point at which spherical particle backscattering mechanisms first come into prominence during snowflake melting. The traditional (S-band) radar bright band peak occurs low in the melting region, just above the lidar dark band minimum. This position is close to where the W-band reflectivities and Doppler velocities reach their plateaus, but well above the height where the S-band Doppler velocities stop increasing. Thus, the classic radar bright band was found to be dominated by Rayleigh dielectric scattering effects in the few largest melting snowflakes that fell the fastest and melted the slowest.

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† Chosen by the Editors of *Geophys. Res. Lett.* to be a **Highlight of This Issue**.